



# A web-based participatory GIS (PGIS) for offshore wind farm suitability within Lake Erie, Ohio



Addisu D. Mekonnen<sup>a,\*</sup>, Pece V. Gorsevski<sup>b</sup>

<sup>a</sup> Department of Geology, Bowling Green State University, Bowling Green, OH 43403, USA

<sup>b</sup> School of Earth, Environment & Society, Bowling Green State University, Bowling Green, OH 43403, USA

## ARTICLE INFO

### Article history:

Received 21 March 2014

Received in revised form

7 August 2014

Accepted 17 August 2014

### Keywords:

PGIS

Spatial decision support system

Offshore wind farm suitability

Borda method

Decision alternatives

Multiple criteria evaluation

## ABSTRACT

This study presents the design and implementation of a web-based Participatory Geographic Information System (PGIS) framework intended for offshore wind suitability analysis. The PGIS prototype presented here integrates GIS and decision-making tools that are intended to involve different stakeholders and the public for solving complex planning problems and building consensus. Public involvement from the early planning stage of projects with a spatial nature is very important for future legitimacy and acceptance of these projects. Therefore, developing and executing a system that facilitates effective public involvement for resolving contentious issues can help in fostering long-lasting agreements. The prototype here is a distributed and asynchronous PGIS that combines a discussion forum, a mapping tool and a decision tool. The potential strengths and benefits of this PGIS are demonstrated in a hypothetical case study in Lake Erie, northern Ohio. In the hypothetical case study, participants evaluate the importance of three decision alternatives using different evaluation criteria for expressing their individual preferences. The individual preferences are aggregated by Borda Count (BC) method for generating the group solution, which is used for synthesizing the different evaluation aspects such as the importance of criteria, ranking of the decision alternatives and planning issues related to environmental and socio-economic concerns from the participants.

© 2014 Elsevier Ltd. All rights reserved.

## Contents

1. Introduction	163
2. Methodology	164
2.1. The conceptual framework	164
2.2. System architecture	165
2.3. Study area	166
2.4. Decision making alternatives	167
2.4.1. Bird habitat	168
2.4.2. Fish habitat	168
2.4.3. Sport fishery effort	169
2.4.4. Commercial fishery effort	169
2.4.5. Utilities (transmission)	169
2.4.6. Population density	169
2.4.7. Navigable waterways	169
2.4.8. Distance from shore	169
3. Results	169
4. Discussion	173
5. Conclusions	175

\* Corresponding author.

E-mail addresses: [addisum@bgsu.edu](mailto:addisum@bgsu.edu) (A.D. Mekonnen), [peterg@bgsu.edu](mailto:peterg@bgsu.edu) (P.V. Gorsevski).

Acknowledgments.....	176
References.....	176

## 1. Introduction

Global warming resulting from human-induced emissions poses important policy challenges that can have significant implications for macroeconomic stability and economic well-being. Today's economy, which is mainly based on depleted fossil fuels, minerals and oil, may not be sustained if technologies remain constant while energy demands increase substantially [1–3]. The need to control human-induced atmospheric emissions of greenhouse gases requires development of other clean and renewable sources of energy. Renewable energy sources (RES) include replenishable natural resources such as geothermal, solar, bioenergy, ocean, and wind [3–6]. Among these RES, currently wind energy is given the most attention due to its widespread distribution, economic viability, significant market value, potential in power generation, and presence of advanced technology [7–10].

Offshore wind energy in the U.S. represents one of the largest RES. Thus, developing an offshore wind generating capacity is one of the most important steps for reducing global warming. For instance, some of the future plans of the U.S. Department of Energy (USDOE) examine the technical feasibility to generate 20% of the country's electricity demand from wind energy by 2030 [11,12]. Short term implementation of those plans suggests that net generation from wind power increased by 28.1% from 2009 to 2010, bringing its share of total generation to 2.3% [13]. Offshore wind energy development in the U.S. is in its early stage; however, there are some projects which are in the planning phase. These include the Cape Wind project (Massachusetts), the Blue-water Wind project (Delaware), the LIPA offshore wind park (New York), and the Galveston offshore wind project (Texas) [4,10,14].

Over the last decade, the world's wind power generation capacity has been growing rapidly. This increase is due to implementation of federal policy initiatives promoting the development of offshore wind farms and other advancements achieved by wind turbine technologies such as efficiency and scalability [1,4,15]. At present, there is an increasing interest in development of offshore wind farms due to several advantages: stronger and constant offshore winds that exist in the offshore environment; closeness to coastal urban load centers, where most electrical energy demand exists and opportunities for wind development on land are limited and efficiency of the offshore wind turbines, which can produce more electricity and can maintain higher levels of electricity generation for longer periods of time [4,7,16–20].

One of the major problems in offshore development is identifying the appropriate site for wind energy farms. Determining wind farm site suitability is a difficult, complex, and protracted process that requires evaluation of many different criteria [1,21] since it combines environmental, economic, and social considerations. Environmental considerations are important and are routinely carried out for wind farm establishment [4,10]. For example, some environmental impacts of wind farms include turbine noise, visual effect and esthetic and other impacts on humans, and effects on ecosystems, including the killing of wildlife, especially birds and bats [3,4,17]. Economic considerations in the siting of wind farms include the costs associated with the acquisition, development, and operation of the site [1,19]. Social and political considerations are related to acceptance of a proposed offshore wind project by residents along the shore, other stakeholders from tourism and fishing industries, and policy makers. Their concerns include fear about harm to the local environment leading to negative impacts

on the fish stocks, and loss of property value and income from tourism [22–24]. The differences in viewpoints among stakeholders and the spatial nature of the information regarding offshore wind siting problems require a tool that can handle these issues effectively.

In recent years, Geographic Information System (GIS) has become a major tool used to select the most suitable sites for onshore and offshore wind installation [25]. GIS methods for wind studies have been used in many countries around the world such as China [26], Vietnam [27], Taiwan [28], India [29], Turkey [30], Greece [18,31,32], Spain [33,34], Denmark [35], Netherlands [36], England [37,38], Brazil [39], Australia [40], and U.S. [41,42]. Within this context, the relevance of GIS for decision support systems (DSS) for locating suitable sites was first tested by Voivontas et al. [31]. Following this work a study from UK aimed at understanding the factors (decision criteria) necessary to determine site suitability for wind farms [43]. Subsequent DSS studies used predetermined criteria that used different aggregation techniques such as Boolean overlay and weighted linear combination (WLC). The Boolean overlay combines the criteria by logical operators such as intersection (AND) or union (OR) while the WLC applies numeric standardization before the criteria are aggregated by weighted average [42,44–46].

For instance, Beacham et al. [47] used Boolean overlay analysis in ArcGIS to identify suitable offshore wind sites in South Carolina. In this study, the raster format criteria were reclassified as suitable (1) and non-suitable (0); then they used Boolean multiplication of the reclassified layers to identify suitable sites. Another study accomplished by Schillings et al. [48] illustrated the use of a web-based spatial decision support system (SDSS) to locate and assess offshore wind potential at the North Sea. This SDSS tool uses overlay analysis of raster layers weighted by users' inputs to generate the final offshore wind farm suitability map. Similarly, Vagiona and Karanikolas [18] used GIS and multi-criteria decision making (MCDM) to identify offshore wind sites in Greece. In this research, Vagiona and Karanikolas [18] applied constraints to all coastal areas to identify places that did not fulfill a certain set of criteria and excluded them from further analysis. Then they used the Analytical Hierarchy Process (AHP) and pairwise comparison of the evaluation criteria to determine weights that show the importance of each criterion [45]. They also performed pairwise comparisons of the candidate sites with respect to each criterion, generating weights, and then aggregated the weights for each candidate site from each criterion to locate the most appropriate sites for an offshore wind farm.

This integration of GIS capabilities and MCDM techniques is also known as the SDSS framework [49,50]. Such frameworks are often extended to accommodate collective group decision making where individuals involved in the decision making process can articulate their individual preferences for the decision problems in the process. The potential of this integration accommodates for Collaborative Spatial Decision Support System (CSDSS) where individuals are united by a common issue-driven interest that acknowledges the complexity of geographic realities in the solution process. For example, Gorsevski et al. [42] demonstrated a prototype for this collaborative group-based SDSS for wind farm selection for regional planning using traditional GIS. The framework integrated environmental and economic criteria to develop a hierarchy for wind farm siting through WLC techniques and GIS functionality. The maps created by the individual's preferences

were aggregated for producing a group solution and subsequent sensitivity analysis that intended to examine conflicting areas associated with the final solution from all participants.

Traditional GIS technologies have been used for local and regional planning in the past; however, their complex nature coupled with a requirement to involve key players (interest groups) in the planning process limits their uses [51]. According to Jelokhani-Niaraki and Malczewski [52], these key players are the stakeholders who are affected by the consequences of the planning decision. Thus, for the planning process to be effective, it is very important to involve different groups of stakeholders [53]. In recent years, an important GIS trend suggests the importance of the development of a simplified Graphical User Interface (GUI), which is capable of engaging different groups of stakeholders as a “community” in the planning process [51]. This approach, also known as Participatory GIS (PGIS), involves public participation so that the decision-making process becomes more democratic and unbiased. PGIS is, therefore, an attempt to simplify and bring GIS from a “close” expert oriented to an “open” user-oriented environment and utilize its technologies in the context of the needs and capabilities of communities that will be involved with and affected by development projects and programs [54,55].

According to Balram and Dragičević [56], PGIS application in community planning has bridged the gap between planning and geographic information science. The decision-making process in PGIS also involves information exchange, discussion and negotiation among stakeholders in order to clarify, refine, and resolve the spatial problem in hand. PGIS integrates people, geographic information data, exploratory tools and structured discussion in order to use and maximize the knowledge, expertise, and experience of multiple stakeholders [53,57–59].

Trang [54] and Meng and Malczewski [60] explained how PGIS practitioners use a public participation ladder as the conceptual framework to guide public participation. In this ladder, non-participation is put at the base of the ladder while higher levels of public participation at the top. The public participation increases as the ladder level increases, leading to empowerment of the public with more control of the decision-making process. The advancement of internet technologies in recent years is leading PGIS implementation in a web-based environment (Web-PGIS), which provides an easy way for sharing public opinion with decision makers without any place and/or time limitation by enhancing the level of public involvement [61,62].

The Web-PGIS framework has addressed one of the problems observed in traditional GIS by allowing participants to express their views anonymously, without any fear and confrontation from anyone [60]. Research shows that implementation of web-based PGIS can be achieved in various application domains such as onshore wind farm planning [37,38], regional social networking [63] and flood risk analysis [64]. Berry et al. [38] developed an application which integrates wind farm sites visualization mapping tool and a web-based survey tool which facilitates public participation in wind farm planning. The focus of this research is aimed to quantify potential visual impacts of proposed wind farm planning using web-based mapping and digital landscape visualization techniques. The results from the survey are used to evaluate the effectiveness and dissemination of wind farm visualizations and to enhance public participation in the wind farm planning process. On the other hand, Simão et al. [37] developed a conceptual system framework for web-based PGIS that combines an information area, a multi-criteria spatial decision support system (MC-SDSS), and an argumentation map. The PGIS module so called Web-based Participatory Wind Energy Planning (WePWEP) supports collaborative and spatial planning through the information area that facilitates both problem exploration and discussion of alternative solutions. The MC-SDSS enables interactive and iterative learning about the

nature of the problem through user inputs which are required for setting the relative importance of the decision criteria that determines the assignment of feasible sites. The argumentation map supports and stimulates the sharing of opinions associated with the interests behind the users' preferences. Other research by Jelokhani-Niaraki and Malczewski [52] and Boroushaki and Malczewski [61] presented web-based prototypes that allow users to set weights of evaluation criteria for decision alternatives under consideration and generate both individual and aggregated group solutions. Decision alternatives represent the basic structure of a decision problem that is used in the selection of a given decision maker's course of action [50]. Yet to date, little research has been done in the implementation of web-based PGIS decision alternatives for wind farm site selection applications. Therefore, this limitation has stimulated the current research; this new line of research supports the evaluation of integrated web-based decision alternatives using public participation through web-based PGIS intended for offshore wind farm site selection.

In this research project, a custom-built, web-based PGIS tool was developed and its capabilities are demonstrated using a hypothetical dataset that could be generated in real settings by potential stakeholders. The proposed tool in this research has some similarities to the Simão et al. [37] WePWEP framework but it offers distinctive features. While WePWEP determines the assignment of feasible sites by evaluating relative importance of the decision criteria, the proposed approach here evaluates the best alternatives of those feasible sites and further complements this previous work. The evaluation of the decision criteria in the WePWEP tool uses a weighting scale that ranges between 0 and 100, which can be cumbersome, especially for non-expert GIS users, while the approach here is based on ranking that simplifies the weighting scale. In addition, in this approach the results from the group scores from the decision alternatives and the frequency of criteria selection are communicated real-time through simple chart statistics that is comprehensive for common users.

Thus, the potential of the tool is illustrated by evaluating three predefined decision alternatives using various evaluation criteria in the southwestern part of Lake Erie, Ohio. The three main components that are emphasized in the illustrated tool include: discussion forum, mapping tool and decision tool. The discussion forum is used to facilitate communication and debate among users regarding different criteria before they use the decision tool. The map tool is used in conjunction with the discussion forum for exploration and visualization of the decision alternatives associated with different criteria while the decision tool allows participants to make their decisions by ranking the decision alternatives using different sets of criteria and cast their votes. The methodology, the proposed conceptual framework, and the system architecture are discussed in the sections below.

## 2. Methodology

Implementation of the prototype PGIS tool involves configuration of the client-server environment, development of the database which serves as storage of both spatial and non-spatial data, development of the different components including forums, spatial maps and a decision module, and their integration in the web-based framework. In the next section, the conceptual framework of the proposed web-based PGIS and the system architecture are discussed.

### 2.1. The conceptual framework

The advantage of implementing PGIS in a web-based environment is that it allows a group of people to interact about common interests, tasks and ideas through easy access and integration of

different tools [58,65]. Some of the features that are present in an effective PGIS are designed to support communication and collaboration for a community of non-technical users using spatial data visualization and decision analysis modules [66].

In this research, the proposed conceptual framework is a web-based PGIS for ranking decision alternatives associated with offshore wind farm site selection, which contains modules including visualization through mapping, collaboration through discussion forum, and a voting module for decision making purposes through an asynchronous and distributed environment. An asynchronous and distributed environment refers to a system that is designed specifically to facilitate user participation during different-time and different-place environments, which improves turnout and involvement in web-based collaborative decision making [36].

The integration of the mapping and the decision tools in the proposed framework follows a loose coupling (ad hoc linkage) approach in terms of data exchange between different modules. This approach also has the capability to combine functionalities of different tools by sharing data in a web-based environment [49,52]. In the system, the decision tool and mapping tool share the same data, which is stored in a database while the communication tool runs independently. The literature suggests different communication tools such as the Argumentation Map (“Argumap”) that integrates geographically referenced discussions, and a web-based GIS capable of structuring debates with spatial elements in asynchronous online discussions [67,68]. However, the prototype in this study uses a communication tool customized by a .NET forum for the purpose of easy customization and integration with the proposed ASP.NET (Active Server Page) development environment used here.

The most common way of achieving a distributed and asynchronous environment for web-based PGIS is through the implementation of a client-server architecture. In this architecture, the client requests different services such as mapping, communication, decision analysis, data processing, and data storage, while the server provides the services [51,52,69]. Implementations of a client-server architecture were implemented in different studies including urban planning [60,70], tourism development [71], transportation improvement program [72], and watershed management [73,74] where the chief objective of the PGIS is to involve different grassroots and community-based groups for broadening public involvement in policymaking. The following section illustrates the system architecture of the proposed prototype which uses ideas from existing PGIS frameworks.

## 2.2. System architecture

Fig. 1 illustrates the conceptual PGIS framework of the thin client-server architecture. This approach is fully “server-side”

processing that facilitates robust management and deployment of the system with easy data update, integration, and implementation [65]. The client-server adopted here is a three-tier system configuration, which is the fundamental framework for the model design that segments the application into three tiers of services. The advantages of the three-tier system architecture over other systems includes high security, performance, scalability, and reusability of modules and system services [58,74,75]. In the current implementation, the three-tier architecture is composed of the Presentation, Business Logic or Middle, and Data tiers. The Presentation tier is the top-most level of the system and used by participants to interact with the system using simple web browsing interface. The main function of the interface is to translate and interpret tasks and results that are comprehensive for the users. The web server, Internet Information Services (IIS), and ASP or Servlet connectors, which facilitate the communication between the Presentation client tier and the Data tier, are under the Business Logic tier. In the prototype, the Business Logic tier integrates different modules such as the decision tool, .NET classes, ArcGIS server and the communication tool. This tier coordinates the application processes such as decision making, evaluations and calculations that are used for data processing between the two adjacent tiers. The third tier is the Data or Database tier, which is used to store and retrieve both spatial and non-spatial information that is passed back to the Business Logic tier and then back to the user. In this implementation, the Data tier includes two main components: PostgreSQL and MS SQL server. The PostgreSQL uses geodatabase and tables to organize the spatial data related to users' information and their preferences. A one-to-many relationship is maintained between a user and related tables. The PostGIS plug-in stores and manages the spatial data in the PostgreSQL database which is subsequently accessed by ArcGIS Server which is the mapping server. Lastly, the MS SQL relational database stores the non-spatial information from all debates posted by the participants associated with the communication tool. Here the data flow between the tool's interface and the database is handled by the .NET Framework Data Provider for SQL Server connection string.

The ArcGIS Server mapping server is used for creating and managing GIS Web services, applications, and for accessing spatial data stored in the PostgreSQL database, where ArcGIS Viewer for Silverlight is used to deploy robust web applications. The two main components of ArcGIS Server that are involved in the process are server object manager (SOM) and server object container (SOC). The SOC machine hosts the server objects (services) while the SOM manages the set of server objects that are distributed across one or more SOC machines. When the SOC receives a request from the SOM for the mapping service; it processes the request and returns back the result to the SOM. Then, the SOM

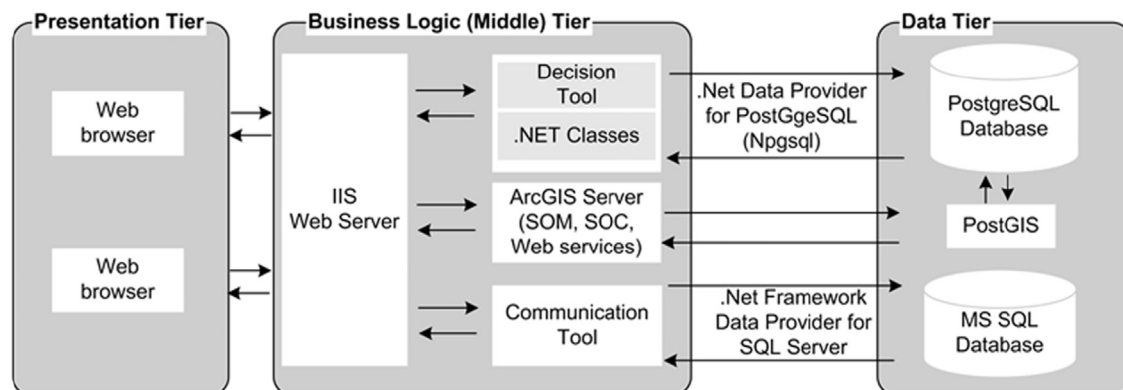


Fig. 1. System architecture.



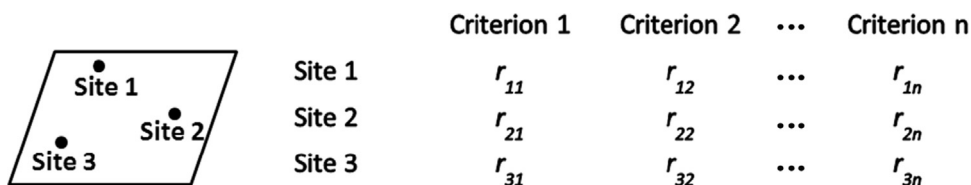


Fig. 2. Relation between alternatives and criteria.

presents the map to clients through the Representational State Transfer (REST) in the ArcGIS Viewer for Silverlight. REST is a set of system architecture principles that facilitates data transfer between client and server over a network using standard protocols such as Hypertext Transfer Protocol (HTTP).

In the prototype, the decision tool is developed using ASP among different.NET classes. It also uses the .NET Data Provider for a PostgreSQL (Npgsql) connection string to communicate with the database. The decision tool implements Multi-Criteria Decision Analysis (MCDA), also referred to as Multi Attribute Decision Analysis (MADA), which deals with decision problems from a number of alternatives. The tool accepts users' preferences, such as criteria and rank of decision alternatives based on the selected criteria, and stores the data in the PostgreSQL database. Moreover, it is also responsible for retrieval of data from the database and presentation of the analysis results to the users.

MCDA is a decision-support process that provides procedures and techniques to structure and evaluate complex problems by assessing a set of alternatives using different criteria. In MCDA, the criteria are evaluated based on their relative importance to assess the problem in hand [50,61,76]. According to Malczewski [49]; Jelokhani-Niaraki and Malczewski [52]; Boroushaki and Malczewski [61], the capabilities of MCDA and GIS can be integrated to facilitate participatory spatial decision making. As a result of this integration, participants can explore and visualize the location of alternatives, and rank or weight these alternatives based on the preferred criteria.

Fig. 2 shows the relation between three spatial alternatives associated with different site locations and a number of different criteria. In this figure, the matrix of criteria and alternatives illustrates the fundamental flow of the spatial MCDA process, which requires the assignment of a rank/weight to each of the alternatives based on the selected criterion. The ranking/weighting values in this figure are represented as  $r_{ij}$ ; where  $i$  is the  $i^{\text{th}}$  alternative and  $j$  is the  $j^{\text{th}}$  criterion. Table 1 shows the calculated scores for the alternatives where the end result of this process represents an ordered ranking of alternatives. In this study, the data values associated with each of the alternatives are used to calculate the scores by implementing the Borda aggregation method [42,77–80].

Borda's method or Borda Count (BC) was first introduced by a French scientist named Jean Charles de Borda at the end of the 18th century [42,77–80]. BC represents a social choice method that is generated by a large group of people for decision making purposes; this method expresses properties called anonymity, neutrality, and consistency in the social choice literature [79]. This "positional" method assigns a score corresponding to the positions in which an alternative appears within the ranked list of preferences. For instance, if there are  $N$  numbers of alternatives under consideration, then the alternative that is ranked first gets  $N-1$  points and the alternative ranked next to the first ranked alternative gets  $N-2$  points. This process of assigning scores continues up to the last ranked alternative that gets zero points. Subsequently, the points assigned to each alternative are summed up in order to calculate the total score and identify the ranking order. Thus, the alternative with the highest total score is considered to be the most important.

Table 1

Calculated scores and ranks after MCDA is performed.

	Criterion 1	Criterion 2	Criterion n	Score	Rank
Site 1	$r_{11}$	$r_{12}$	$r_{1n}$	Score <sub>1</sub>	Rank <sub>1</sub>
Site 2	$r_{21}$	$r_{22}$	$r_{2n}$	Score <sub>2</sub>	Rank <sub>2</sub>
Site 3	$r_{31}$	$r_{32}$	$r_{3n}$	Score <sub>3</sub>	Rank <sub>3</sub>

Table 2

Numerical example of 3 alternatives and 21 participants.

Ranking	Alternatives			Points
	a	b	c	
1 <sup>st</sup>	8	7	6	2
2 <sup>nd</sup>	0	9	12	1
3 <sup>rd</sup>	13	5	3	0
Number of participants	21	21	21	

In this study, the decision alternatives are ranked from first to third position in terms of preferred importance. To get a clear understanding, the method is further explained using a numerical example. Using the three alternatives (a–c) and 21 participants as shown in Table 2, alternative "a" is ranked in first position by eight (8), second position by zero (0), and third position by thirteen (13) participants respectively. The points assigned for each rank range for 0–2 where score of 2 is assigned for all first ranked outcomes, a score of 1 for all second ranked outcomes, and 0 for all third ranked outcomes. Hence, the total score for each alternative is summarized below by applying the Borda rule. As shown below, the Borda score for alternative "c" is higher than all the other alternatives. A careful observation of Table 2 shows that alternative "a" which has the most first ranked outcomes is also the one with the strongest opposition since 13 outcomes reside in the last position. Therefore, alternative "c" is the most important and highly favored by the participants.

$$\text{Alternative "a"} = (2 \times 8) + (1 \times 0) + (0 \times 13) = 16$$

$$\text{Alternative "b"} = (2 \times 7) + (1 \times 9) + (0 \times 5) = 23$$

$$\text{Alternative "c"} = (2 \times 6) + (1 \times 12) + (0 \times 3) = 24$$

However, the merit of Borda's method is in the aggregation of participants' scores where individuals collectively make a choice from a set of presented alternatives. Such an approach achieves a consensus solution by preventing contentious participants, who rank some alternatives very high and some very low, from holding dominance while it also promotes a consensual solution.

### 2.3. Study area

The hypothetical study area is located in northern Ohio along the western Lake Erie shore (Fig. 3). Five counties in Ohio are included in the study area, including Lucas, Ottawa, Sandusky, Erie, and Lorain. According to the US Census Bureau's report [81], the total population in these five counties is more than 0.9 million, which is equal to 8% of the State's total population. Major cities

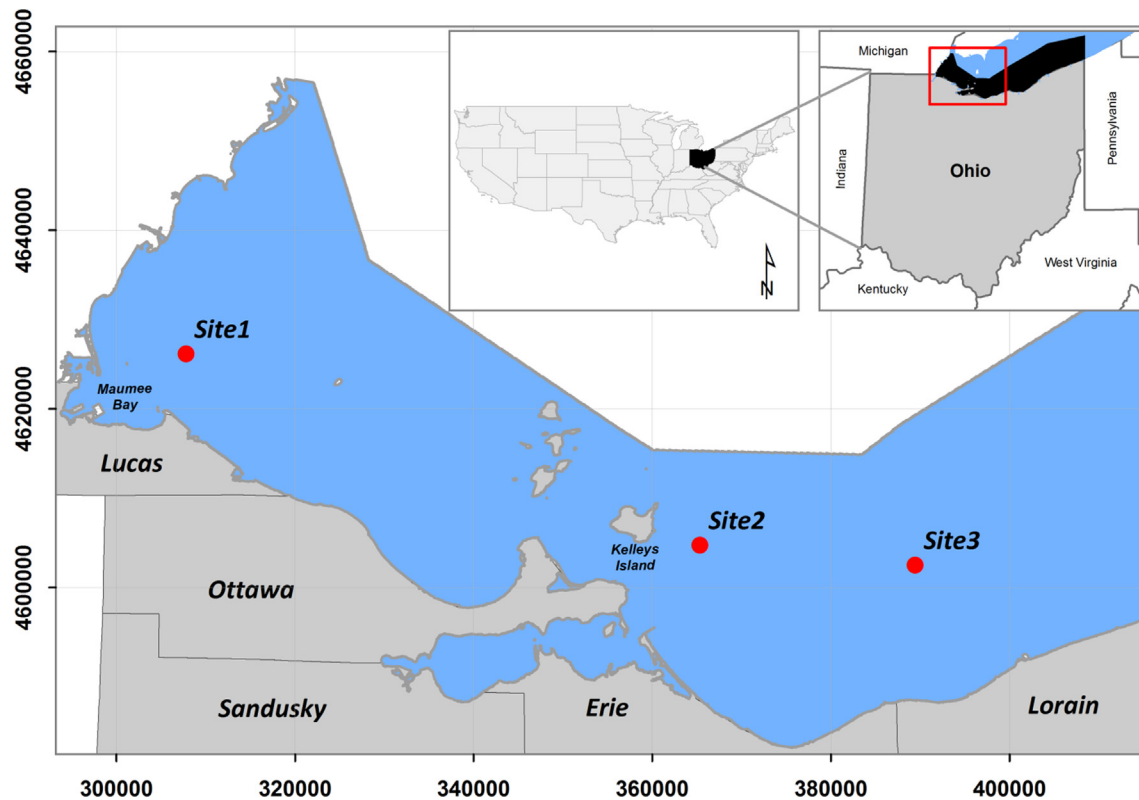


Fig. 3. Location map of the study area.

and towns located in the study area are Sandusky, Toledo, Port Clinton, and Monroe.

Lake Erie is a fresh water lake, it is the shallowest of the Great Lakes (averaging only 19 m), and overall the smallest by volume. Lake Erie is divided into three basins: western, central, and eastern. The study area covers the western and central parts of the lake. The average depth of the western part of the lake is 10 m and the central part is 18.5 m [82,83]. The study area is characterized by strong wind with an annual average speed of 7–7.5 m/s, which is highest in November and lowest in July, and is favorable for offshore wind energy generation. The area is characterized by high ice concentration in mid-December to mid-February, with the ice concentration decreasing from mid-February to mid-April [84,85]. The wetlands of Lake Erie support a variety of plant and bird species. For instance, according to Herdendorf [83], there are over 300 plant species in the aquatic and wetland habitats of western Lake Erie. The Ohio National Wildlife Refuge (ONWR), which is known for its rich biodiversity, is part of the study area. Moreover, birds such as waterfowl, wading birds, shore birds, gulls and terns, raptors and perching birds use Lake Erie wetlands for migration, nesting and feeding.

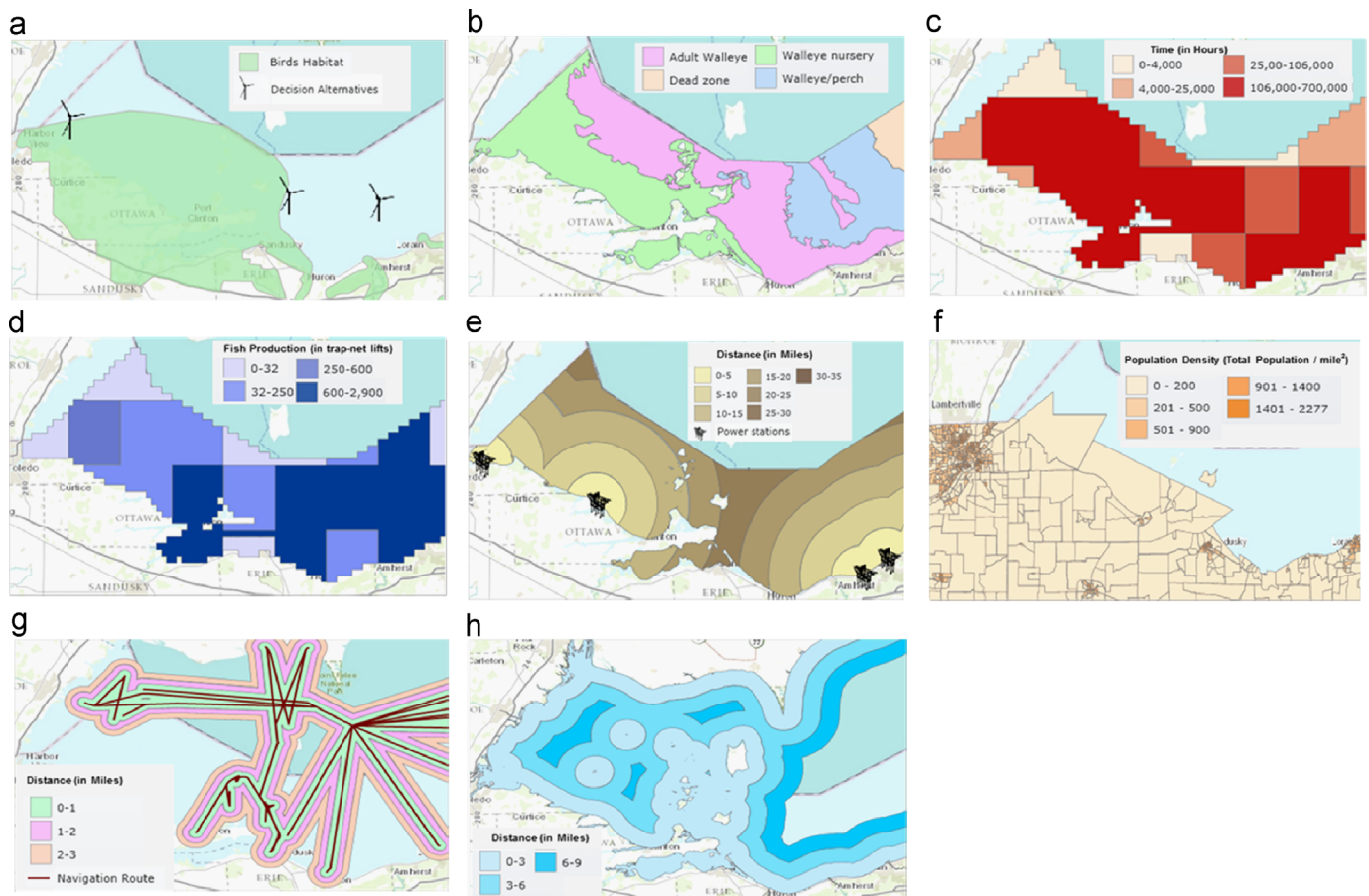
The U.S. Department of Energy [86] reported that the average annual electric consumption of Ohio is around 154,145 million kWh and it shows a 1.4% increase annually. In the Great Lakes Region, there is a potential of 700 GW of offshore wind energy production. Of this significant level of potential wind energy from Lake Erie, it would be possible to generate up to 45 GW in Ohio [11]. This energy is equivalent to 98,550 million kWh with a 25% production capacity. The 25% of production capacity is used to reflect other restrictions that may impede farm deployment due to competing uses, engineering design, weather conditions, fishery, environmentally sensitive areas, and migratory birds. It would also be possible to cover around 63.9% of the state's energy consumption with this energy. According to the Lake Erie Energy Development Corporation [87],

Lake Erie is a favorable and cost effective location for offshore wind farm installations.

In the study area there are three decision alternatives to be assessed by the participants. As shown in Fig. 3, “Site 1” is located near Maumee Bay, “Site 2” is located east of Kelley's Island, and “Site 3” is located off the far northwestern corner of Lorain County. These decision alternatives were identified since they fulfill the wind resource required for offshore wind farm development, which is at least 7 m/s at a turbine height of 90 m (or 262 ft) above the local surface [11]. To demonstrate the functionalities of this prototype tool and to illustrate the potential application for evaluation of alternatives for wind farm selection, the simple hypothetical scenario uses a total of three sites for ranking of alternatives.

#### 2.4. Decision making alternatives

SDSS for suitable offshore wind site selection involves ranking of the decision alternatives based on different evaluation criteria. In this study a total of eight evaluation criteria were used, including: Population Density (PD), Bird Habitat (BH), Commercial Fishery Effort (CF), Distance from Shore (DS), Fish Habitat (FH), Navigable Waterways (NW), Sport Fishery Effort (SF), and Utilities (UT) (Fig. 4). The criteria used in this demonstration were identified based on a detailed literature review, US offshore wind energy siting legislation, and data availability [7,11,12,88,89]. For instance, the policies that have affected offshore wind development in federal waters include the Outer Continental Shelf Lands Act (43 U.S.C. 1337) and the National Environmental Policy Act (NEPA) (42 U.S.C. 4321–4347). In the case of the state's waters that surround the Great Lakes, the Coastal Zone Management Act of 1972 (Pub.L. 92-583) administered by the National Oceanic and Atmospheric Administration (NOAA) is the only policy that is designed to set up a basis for coastal zone management plans



**Fig. 4.** Evaluation criteria (a) bird habitat, (b) fish habitat, (c) sport fishery effort, (d) commercial fishery effort, (e) distance from utilities, (f) population density, (g) distance from navigable waterways, and (h) distance from shore.

for preservation, protection, and restoration of wildlife and natural resources. In addition, in this study the evaluation criteria are intended to address different wind farm development planning issues related to environmental and socio-economic concerns, which can impede the decision making process. The consideration of environmental issues helps to minimize any potential ecological impacts, while socio-economic considerations include minimizing construction, operation and maintenance costs and impacts on the local economy and quality of life affected directly or indirectly due to wind farm installation.

BH and FH are under the environmental consideration and the socio-economic considerations include SP, CF, UT, PD, NW, and DS. In this project, rather than fully accounting for all possible evaluation criteria and concerns, the main objective was to demonstrate the flexibility of this PGIS prototype that could be altered by using different evaluation criteria and concerns for different site specific problems and requirements.

#### 2.4.1. Bird habitat

Planning of new offshore wind energy site selection should consider the impact on the natural habitat of birds. The study area is known to possess two national wildlife refuges (NWRs), including Cedar Point and Ottawa NWR's, and three Important Birds Areas (IBA) sites which are included in the American Birds Conservancy list of the 500 most important IBAs in the U.S. [90]. According to Audubon Ohio [91], IBA is a conservable site identified on the basis of its international significance for the conservation of birds at the global, regional or sub-regional level for threatened, congregatory, assemblages of restricted-range and

biome-restricted bird species. As stated by NREL [11] and Baisner et al. [92], the major risks from offshore wind turbines to migratory and resting birds are collisions and mortality, physical habitat loss from displacement, and visual stimulus/avoidance response and barrier effects, including fragmentation of the ecological habitat network (e.g., migration pathways, breeding or feeding areas). Therefore, ideally, offshore wind farms should be located out of bird habitat [84]. In this study, the electronic spatial data of IBA's in vector format was collected from Ohio Department of Natural Resources [93] Office of Coastal Management and used to show the location and proximity of bird habitats relative to the proposed wind farm sites. Therefore, sites that are farthest away from bird habitat are most suitable for offshore wind farms.

#### 2.4.2. Fish habitat

The effect of offshore wind installation on fish habitat is one of the main environmental concerns that should be addressed during wind farm site planning. Fish habitat is disturbed and altered during and after installation of wind farms [11,23,84]. Therefore, it is important to know the fish habitat in the water body ahead of making any further decision on the suitable site. The U.S. Fish and Wildlife Service legislation stipulates that offshore wind sites should be away from fish nursery and spawning areas. These areas are habitat for larval and young-of-year fishes [11]. In this study, four classes of fish including walleye nursery, adult walleye, walleye/perch, and dead zone (absence of habitat) represent the fish habitat map [93]. The walleye nursery class is considered as the least suitable, adult walleye and walleye/perch are moderately suitable, while the dead zone class is the most suitable habitat for wind farms.



#### 2.4.3. Sport fishery effort

The sport fishery effort is a common activity in Lake Erie that is compiled by the average hours targeting walleye and yellow perch using an area of 10-min quadrangle from 2000 to 2006. According to GLWEC [84], in 2006 alone a total of 1.25 million fishing licenses were sold in Ohio, generating around \$1 billion. Of these licenses, one third was sold in the counties along the Lake Erie shore. From the different fish species that exist in the lake, walleye and yellow perch are most popular for sport fishery. The spatial data layer for this criterion was acquired from ODNR [93], which groups the sport fishery map into four classes as 0–4000, 4000–25,000, 25,000–106,000, and 106,000–700,000 h. The classes are based on the total hours spent by people in the areas. Classes with higher average hours are least suitable and classes with lower average hours are most suitable for wind farm development.

#### 2.4.4. Commercial fishery effort

This criterion is related to the amount of fish which is utilized for commercial purposes from the study area. This criterion needs careful attention because Lake Erie is known for its largest fresh water commercial fisheries among all of the Great Lakes, especially because of the lake's relatively mild temperatures and abundant plankton supply which is the basic building block of the food chain [84]. Wind turbine development is opposed by the fishing community fearing for their traditional fishing grounds, which are their livelihood. The fish productivity of an area is measured based on the number of fish harvested, which is measured in trap net lift [84]. ODNR [93] provided the vector map showing the total number of commercial fishery effort trap-net lifts by 10-min quadrangle, from 2000 to 2006. The map was classified into four classes as 0–32, 32–250, 250–600, and 600–2900 trap net lifts. Therefore, suitability decreases from the first class, 0–32 traps, to the last class, 600–2900 traps.

#### 2.4.5. Utilities (transmission)

The third socio-economic factor considered was proximity to utilities or transmission lines. According to GLWEC [84], cable installation has a significant impact on the cost of offshore wind projects. Cable cost is dependent on the project proximity to existing transmission stations. The closer the project site is to existing transmission stations, the less the cable installation cost. Therefore, offshore wind energy developers prefer the closest site to develop so that they may access existing transmission stations easily and deliver energy to customers at a lower cost. In this study, data of existing transmission stations along the shore was collected from ODNR [93]. Thereafter, in GIS using the buffer tool, this distance was calculated from these places in different intervals. The distance was grouped into seven classes as 0–5, 5–10, 10–15, 15–20, 20–25, 25–30, and 30–35 miles. Classes with shorter distances, such as 0–5 and 5–10, are most suitable; classes with medium distances such as 10–15 and 15–20 are moderately suitable; while the other three classes are the least suitable for wind farm installation.

#### 2.4.6. Population density

Population density is assessed based on the number of residents per square kilometer. As stated in HEI [89], when considering population density from an economic point of view, areas suitable for offshore wind energy installation are those which are close to higher population densities. As reported by AWS Truewind [88], these areas are the main consumers of the produced energy. In this study, census tract vector data of the counties, located along the shore, was collected from the US census office to calculate the population density [81]. Then, the population density was calculated in GIS, dividing the total population by the total area of each

census tract. The population density layer was classified into five classes as 0–200, 201–500, 501–900, 901–1400, and 1400–2277. Therefore, sites that are close to a high population density are given higher priority than those which are far away.

#### 2.4.7. Navigable waterways

Offshore wind sites that are located far away from navigable waterways are more suitable sites. These sites will not affect any transportation route in the water body [88,89]. The spatial data for navigable waterways was collected from ODNR [93]. Then, the data was added in GIS to generate buffer zones at 0–1, 1–2, and 2–3 miles intervals. The limitation of the distance into these three zones helps to reduce cost of offshore wind turbine installation and to accommodate concerns related to turbine components transportation to greater distances. Therefore, sites that are in the third zone, which is 2–3 miles, are most suitable, followed by the second zone that is 1–2 miles, leaving sites in the 0–1 mile zone as being deemed least suitable.

#### 2.4.8. Distance from shore

Noise pollution, shadow flickering, and esthetic influence effects on people living along a shore are important concerns for the acceptance of offshore wind farm projects by affected communities. Some claims are that wind turbines close to the shore diminish quality of life, decrease property value, and affect the local economy supported by income generated from recreation and tourism [3,11,89]. As a result, distance from the shore at which wind turbines are going to be installed should be given more attention. In this study, the shoreline data from ODNR [93] was used to generate buffer distance with three classes: 0–3 miles, 3–6 miles, and 6–9 miles.

### 3. Results

The intention of the prototype was to provide a simple interface for non-experienced GIS users. The main components that comprise the prototype were organized under different themes, including a discussion forum, a mapping tool and a decision tool. The easy-to-use interface was based on the principles of web usability, such as guided user interface elements that are easy to follow, and elements of the navigation tool that are arranged logically and which are similar to a traditional web site navigation bar.

Fig. 5 illustrates the PGIS web interface that is associated with the main page of the project, which can be accessed by web browsers such as Internet Explorer, Chrome or Mozilla Firefox. The default web page is used for navigation between different levels that are used for the development of a thorough understanding of criteria associated with different decision alternatives. The main goal of the default web page is to acquaint the participants with the project and the process of selection alternatives for suitable offshore wind farms. As shown in Fig. 5, the default web page contains location map of the case study area and brief description of the main components used in this PGIS.

The “Background” theme presents all the details associated with the project, including the basics of wind energy, the benefits and the concerns associated with wind farms, development of wind projects, the PGIS concept, information regarding the criteria used in the project, and instructions for using the tool. In addition, participants may access a manual which contains a brief explanation of how to utilize the different components in this prototype.

Fig. 6 shows the mapping interface where participants can explore individual criterion associated with decision alternatives. The main purpose of this component is for data visualization, which communicates the spatial extent of the criteria and the



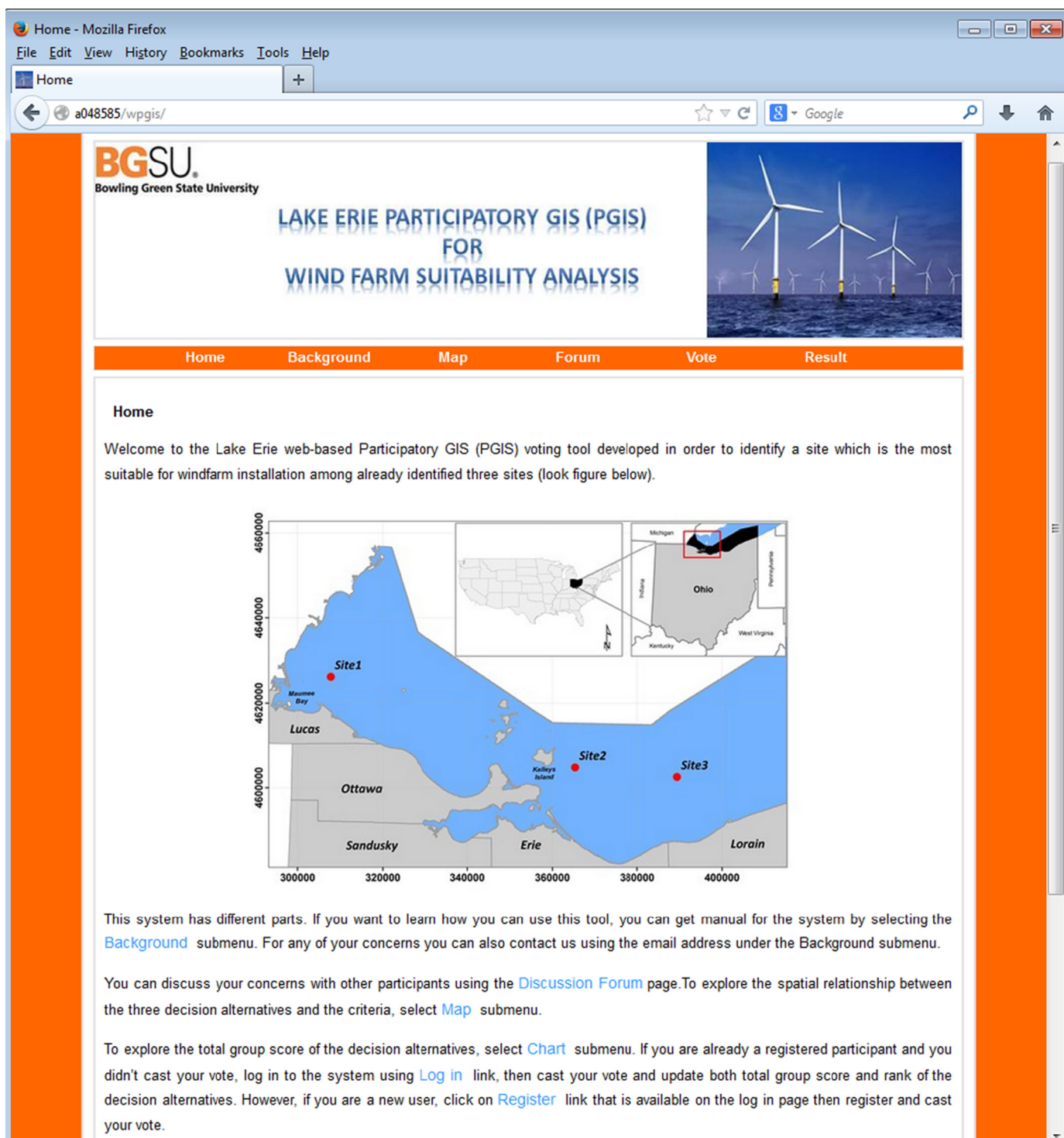


Fig. 5. Home page of the prototype PGIS.

location of the decision alternatives that will drive the process of the decision making. Here the visualization helps with the overall understanding of the spatial criteria that provide valuable insights and reasoning behind the ranking of the decision alternative. The background map information is powered by the Google Maps interactive map interface (API) that helps participants to create a better understanding of location while the familiarity and simplicity of Google Maps helps the general public to participate in a complex decision making planning process. In addition, the system allows for displaying different Google Maps as backgrounds, including roadmaps (normal, default 2D map), satellite

(photographic) maps, terrain (featuring mountains, rivers, etc.) maps, and hybrid (photographic with roads and city names) maps.

In Fig. 6, the easy-to-use mapping interface contains basic mapping functionalities such as zoom and pan shown in the top right corner. Participants can use these tools to manipulate and explore the spatial data associated with different criteria in the case study area. The map content includes a legend display that provides useful narrative and graphic descriptions for understanding what is being viewed in the map. For instance, the figure shows that the "Decision Alternatives" and the "Fish Habitat" layers have been selected in the Map Contents Panel. The "Decision Alternatives"

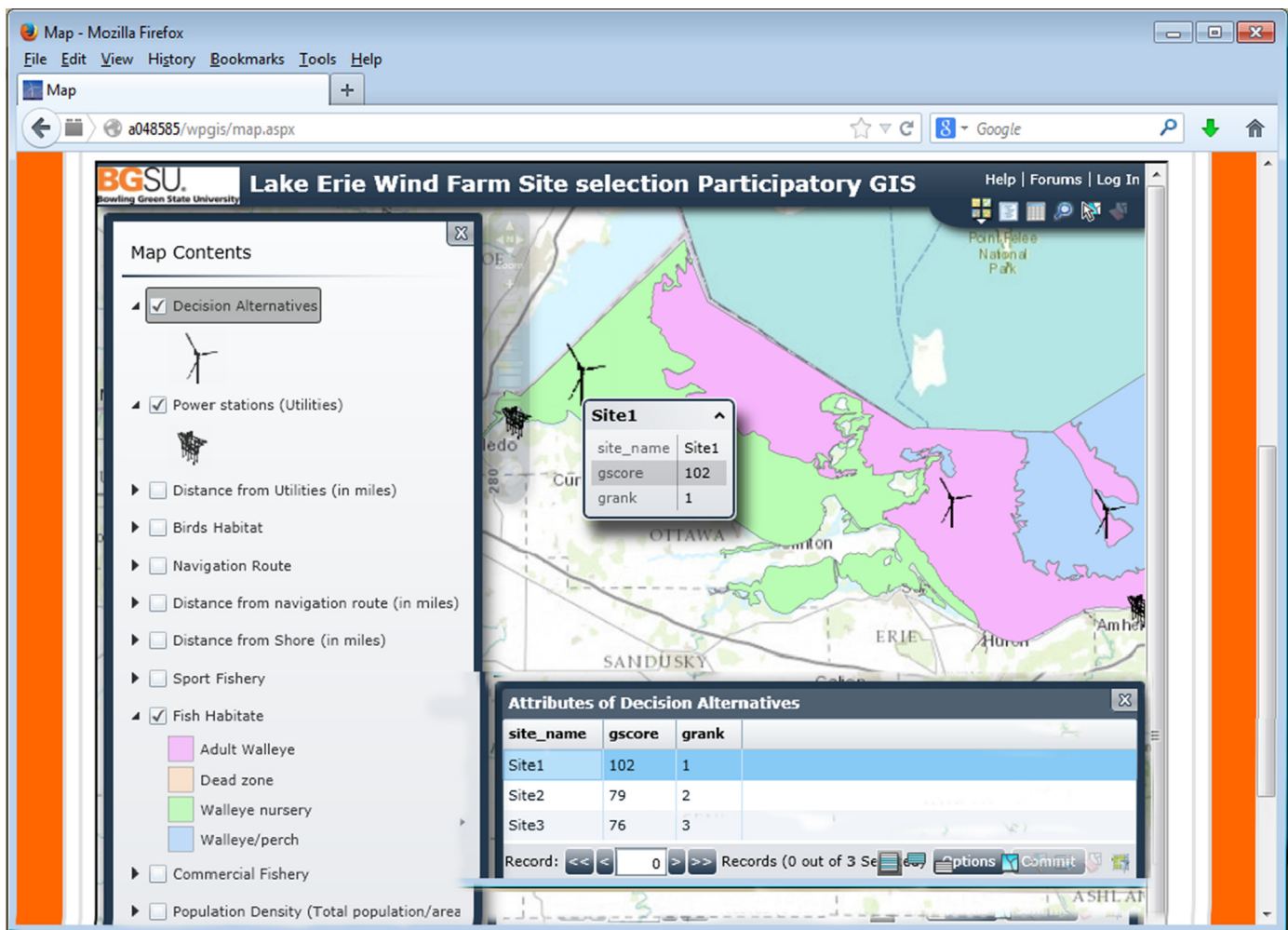


Fig. 6. Mapping tool interface with map contents dialog box and attribute table of the decision alternatives.

layer shows the location for the proposed wind farm locations that correspond to the displayed attribute table. The data from this attribute table is primarily stored in the PostgreSQL database and the table contains information about different geographic features that are used to find, query, and symbolize information. The “Fish Habitat” layer shows the legend and the distribution of the four main species including walleye nursery, adult walleye, walleye/perch, and dead zone, each of which is separated by different colors. In addition, participants can also display or hide map layers for better visualization of the spatial data.

Fig. 7 shows the forum component that is used to facilitate discussion among participants for exchanging views and ideas of spatially-related issues. Specifically, the main objective of this module is to accommodate a diverse array of participants and community members, enabling them to discuss issues such as impacts on the local community, as influenced by the selection of different criteria and alternatives; the module also enables users to generate new ideas based on different feedback. The module allows for an ongoing, asynchronous discussion, so it can help each participant to better formulate his or her opinion, which may evolve throughout the discussion process. Such a module is capable of catering to a large group of participants since it supports various tools such as text, maps, sketches, images and annotations to express and convey users' opinions. In addition, for better integration of the public to participate in the ongoing discussion, an impartial facilitator can guide the discussion process. Some of the tasks for the facilitator may include coordination

of the planning process, advising on the proper use of the tools, providing working materials and nonpartisan information, and encouraging each participant's full involvement in the discussion.

The discussion and interaction among participants precedes the voting module that is used for the ranking of the alternatives by individual participants. Participants are required to register before using the forum and voting module. The registration details from the participants are only used to help with the identification of participants and to collect the voting preferences for the inclusion of criteria and ranking of alternatives.

Fig. 8 shows the decision tool or the voting module for ranking the decision alternatives associated with the selection of a given wind farm location. The decision tool is the core part of the system that is used to collect voting preferences from the participants. Here, the participants can vote on the importance of criteria and the rank of the alternatives. In this study, the ranking method was used due to its simplicity and unambiguousness in collaborative and participatory decision-making [49,52]. For instance, Fig. 8 shows that the two selected important criteria include bird habitat (BH) and commercial fishery (CF). The selection of the criteria activates the ranking information where participants can select the rank for each of the decision alternatives that relates to a specific criterion. Rank 1 indicates the most suitable site, rank 2 the second most suitable, and rank 3 the least suitable location for wind farm installation. For instance, Site 3 is the most suitable location for a new wind farm in relation to the bird habitat criterion whereas Site 1 is the least suitable location. Participants

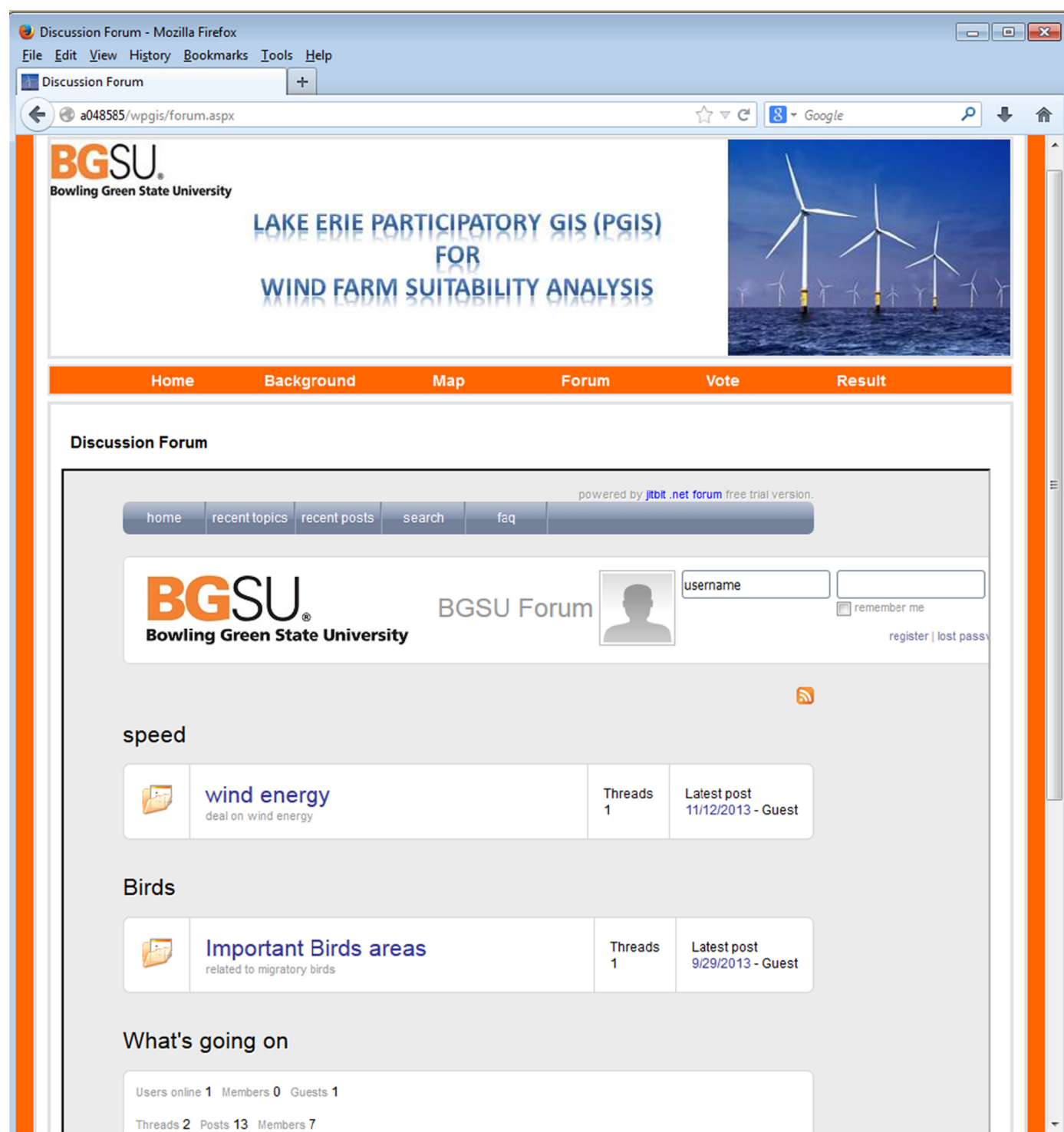


Fig. 7. Interface for the forum module.

can also easily display the mapping module from the decision tool by using the link “Display Map”. This helps participants to see the spatial relationship between criteria and the decision alternatives while using the decision tool.

The flow chart in Fig. 9 highlights the data flow process behind the voting tool. After the participant is logged in, the decision module requires the participant to select the most important criteria, which are used for the ranking of the decision alternatives. Before the information is submitted to the database, the system checks for errors such as selection of at least one criterion and

whether the participant already had casted his or her vote earlier. After the participant submits the vote, the score and voting position of the decision alternatives is calculated by adding the ranks for each alternative from every voter using the Borda Count approach.

Participants can also visualize the voting results using a chart display before and after casting their vote. Fig. 10 shows the scores for the decision alternatives and the importance of the criteria. For instance, Fig. 10 shows that Site 1 is the most suitable decision alternative while Site 3 is the least suitable decision alternative for a wind farm location. Also, the most preferred criteria for the

**BGSU**  
Bowling Green State University

## LAKE ERIE PARTICIPATORY GIS (PGIS) FOR WIND FARM SUITABILITY ANALYSIS

Welcome, Addisu!  
LOGOUT

### Voting

Please select at least one criteria in order to participate in the vote

Rank values indicate that 1-most suitable for wind farm, 2-second most suitable, and 3-the least suitable

[Display Map](#)

\* Required Field

#### Voting Information

Criteria	Site1	Site2	Site3
<input type="checkbox"/> Population Density (PD )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>
<input checked="" type="checkbox"/> Bird Habitat (BH )	<input type="text" value="3"/>	<input type="text" value="2"/>	<input type="text" value="1"/>
<input type="checkbox"/> Navigable Waterways (NW )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>
<input type="checkbox"/> Distance from Shore (DS )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>
<input checked="" type="checkbox"/> Commercial Fishery (CF )	<input type="text" value="2"/>	<input type="text" value="1"/>	<input type="text" value="3"/>
<input type="checkbox"/> Fish Habitat (FH )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>
<input type="checkbox"/> Sport Fishery (SF )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>
<input type="checkbox"/> Utilities (UT )	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>	<input type="text" value="select rank"/>

[View Score](#)

Fig. 8. Decision tool interface.

participants is the fish habitat, while distance from shore and utilities are the most controversial criteria used for the selection of the wind farm location.

#### 4. Discussion

In development of PGIS, the set of evaluation criteria depends on the problem under consideration and suggestions of stakeholders who participate in the planning process. These stakeholders have to be representatives of diverse areas of competence, political and economic agendas, and social values. This can be

achieved by enabling and fostering the most inclusive participation [57,72]. An inclusive participation approach follows the principle of involving representatives from the wider general public as participants while utilizing a nonpartisan facilitator to elicit a well rounded discussion from all participants. Otherwise, if participants and the facilitators are only activists, interested groups, planners and professionals, then the public voice will be biased or dominated by certain opinions that may not be widely representative or wise. Therefore, the public's involvement should be from the earliest stages of the planning process and should be designed to build mutual understanding and consensus among participants [53]. Later, once diverse voices have been considered,



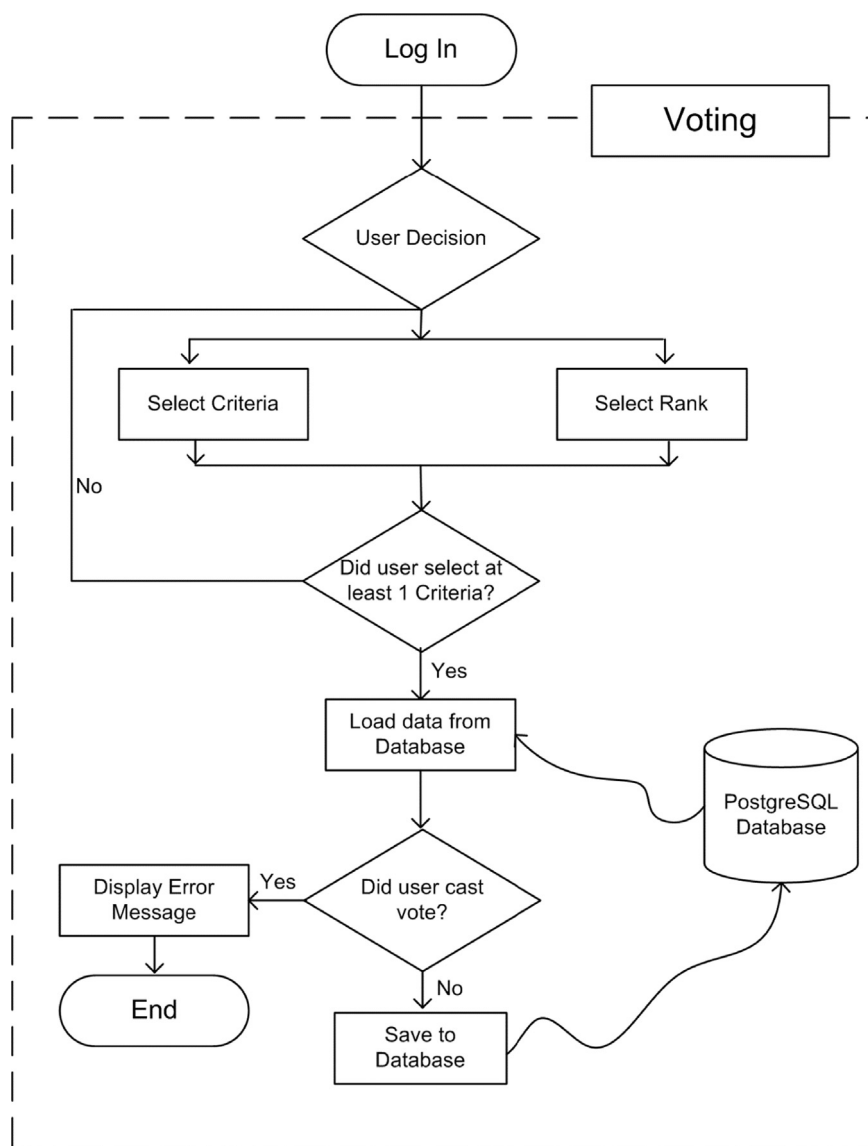


Fig. 9. Data flow in the decision tool.

this also tends to support legitimization and greater public acceptance of the decision process.

Participants can be informed and empowered about the initial idea through different mechanisms such as stakeholder workshops, consensus conferences, deliberative opinion polls, negotiated rulemaking, task forces, and town meetings [94]. However, recently public participation practices are using information technology (IT) for public involvement other than, or in addition to, these traditional methods of participation. The mechanisms described above allow participants to express their concerns and suggest criteria to be considered in the decision-making process. Based on Malczewski [50], the procedure for identifying the criteria should be a multistep iterative process. That is, the process should be done repeatedly to accommodate all of the concerns of the stakeholders.

In this research, the implemented web-based PGIS is flexible and can incorporate different criteria other than the eight criteria which we had already included in the current version of the tool. Adding diverse and alternative criteria could be accomplished by public involvement in discussion forums for selection of goals and criteria that should be considered in the offshore wind farms planning process [60,69,76]. For instance, this module can be used

for idea generation, collection and sorting of ideas and improvement of the planning process based on feedback.

The identification of stakeholders is an important step in developing a PGIS. Determining truly representative stakeholders will better help to address the general public's issues and concerns. Furthermore, it will give added confidence to the stakeholders in how to use the developed system. In this study, the main objective was to demonstrate the potential of web-based PGIS as a SDSS tool using hypothetical scenario without the involvement of stakeholders' opinions in the planning phase. Hence, as a starting point, this research consulted relevant studies to identify some of the criteria that are important in offshore wind farm planning [9,22,24,61,84,89]. A real scenario of PGIS development for wind farm site selection should involve a description of concerns to participants, discussion(s) among participants, setting criteria, and voting on the decision alternatives. During the description of concerns participants will be informed about the problem and will be provided with background information. Then participants will express their concerns regarding any proposed wind farm project during the discussion phase. This stage helps to address Not In My Back Yard (NIMBY) syndrome often associated with suitable wind farm site selection. The criteria set by

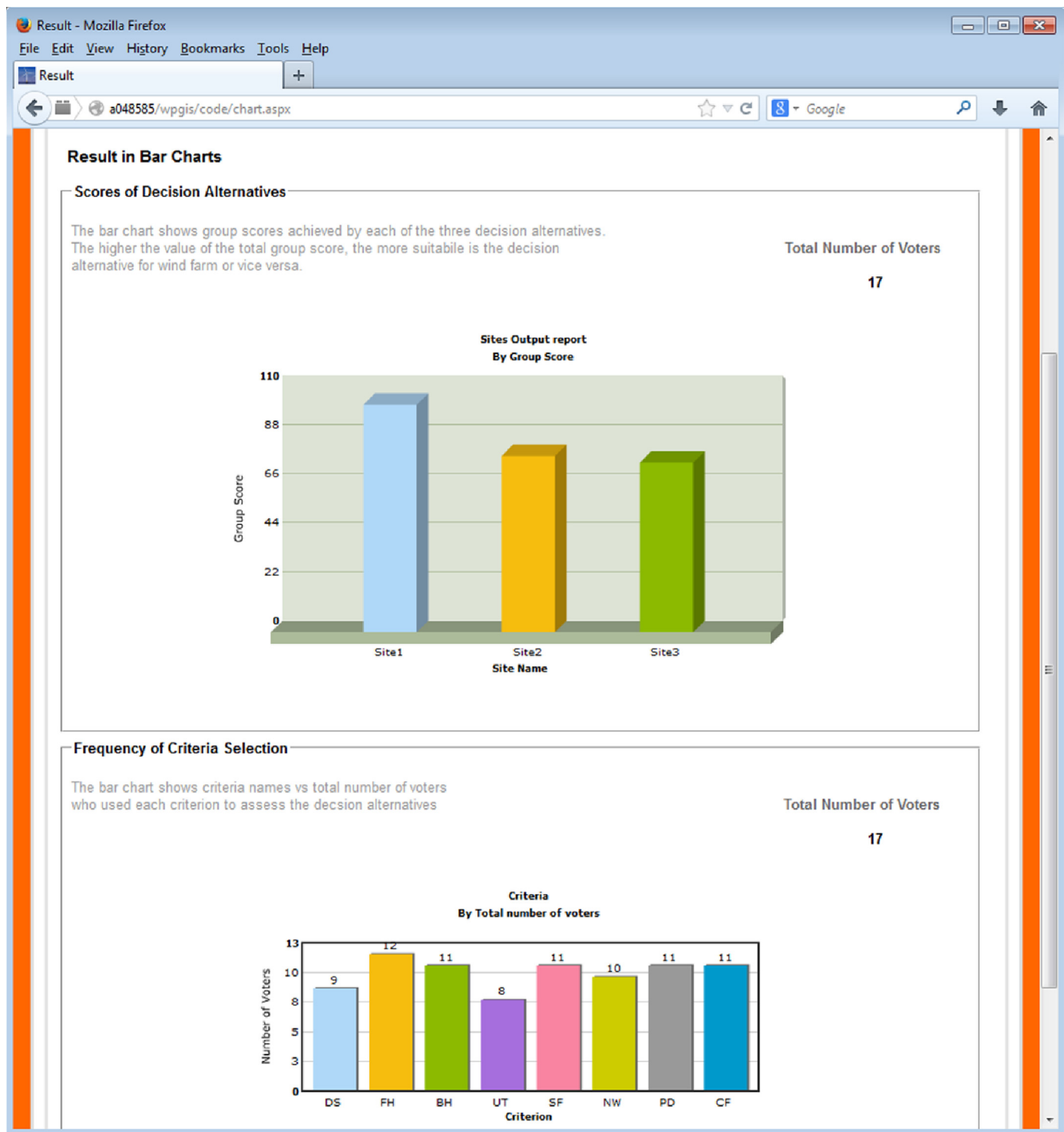


Fig. 10. Charts showing the group score from the decision alternatives and the frequency of criteria selection.

participants will serve as a means to evaluate the decision alternatives. Once common understanding and consensus is achieved among participants regarding the criteria, the next step will be voting for achieving group decision making [72].

There are different approaches that can be followed to use the web-based PGIS in order to achieve group decision making. For instance, nonpartisan facilitators can moderate the forum discussions and guide the process where the voting goal may include the gathering of additional data to measure stakeholder attitudes. Other models are also possible, such as an “open access poll,”

which uses continuous voting (i.e., submitting a voting option on a website), or an “online poll,” which may use a survey in which participants communicate responses via the internet.

## 5. Conclusions

This study demonstrated the design and implementation of a conceptual framework for distributed and asynchronous web-based PGIS. The PGIS framework integrated three components

including a discussion forum, a mapping tool and a decision tool. The potential implementation was illustrated by using a hypothetical case study to show the strengths and the benefits from PGIS in facilitating suitable offshore wind farm site selection in Lake Erie. The hypothetical case study implemented a standard decision-making scenario by ranking three predefined sites or decision alternatives using eight different spatial criteria in a collaborative and transparent way.

The implementation of the proposed framework used a thin client-server environment with three-tier architecture. The final PGIS product of this integration used standard GIS-based multi-criteria evaluation approach that accommodates multi-user environments and supports group decision making. The mapping tool is used for visualization, exploration and comparison of decision alternatives and their corresponding properties such as total score and rank. The decision tool is used to perform ranking of the decision alternatives based on the evaluation criteria using Borda Count (BC) method as a means to calculate the group scores of each decision alternative. Lastly, the discussion forum is used to facilitate communication and debate among participants.

In summary, the intention of this study was to show the potential of a web-based PGIS for offshore wind suitability analysis that integrates alternatives, evaluation criteria, and participants' input using new technological ideas. The strength of this methodology is the flexibility for modification and customization when implemented in different study areas or other applications and problems, which require spatial decision support. Although the system was not fully tested with real stakeholders, the potential implementation to resolve complex issues of important public planning problems was demonstrated through the real-world-based data that we incorporated into the hypothetical scenario that we discussed.

Future recommendations for refinement of this decision-making tool and process include the addition of more modules for dynamic inclusion and exclusion of decision alternatives, different voting approaches, aggregation of individual scores to obtain a group solution, and simplification of the importance of the criteria using sets of linguistic terms such as “low,” “medium,” and “high.” The use of linguistic terms or quantifiers can help with the conversion of human language to be formulated mathematically, which can further simplify the system in terms of its user-friendliness, and encourage wider participation in the spatial decision-making process.

## Acknowledgments

This investigation is part of the Coastal Ohio Wind Project that was supported by the U.S. Department of Energy Award number DE-FG36-06GO86096; the support of this institution is gratefully acknowledged.

## References

- [1] Grassi S, Chokani N, Abhari R. Large scale technical and economical assessment of wind energy potential with a GIS tool: case study Iowa. *Energy Policy* 2012;45:73–85.
- [2] Intergovernmental Panel on Climate Change (IPCC). Special report on renewable energy sources and climate change mitigation (SRREN) 11th Session of Working Group III. Abu Dhabi, UAE; 2011.
- [3] Saidur R, Rahim NA, Islam MR, Solangi KH. Environmental impact of wind energy. *Renew Sustain Energy Rev* 2011;15:2423–30.
- [4] Leung D, Yang Y. Wind energy development and its environmental impact: a review. *Renew Sustain Energy* 2012;16:1031–9.
- [5] Mirhosseini M, Sharifi F, Sedaghat A. Assessing the wind energy potential locations in province of Semnan in Iran. *Renew Sustain Energy Rev* 2011;15:449–59.
- [6] Molina-Ruiz J, Martínez-Sánchez MJ, Pérez-Sirvent C, Tudela-Serrano ML, García Lorenzo ML. Developing and applying a GIS-assisted approach to evaluate visual impact in wind farms. *Renew Energy* 2011;36:1125–32.
- [7] Adelaja A, McKeown C, Calnin B, Hailu Y. Assessing offshore wind potential. *Energy Policy* 2012;42:191–200.
- [8] Coskun AA, Türker YÖ. Wind energy and Turkey. *Environ Monit Assess* 2012;184:1265–73.
- [9] Limpo JR. Assessment of offshore wind energy in Portuguese shallow waters site selection, technical aspects and financial evaluation. (A Master's Thesis Instituto Superior Técnico). Lisbon, Portugal: Universidade Técnica de Lisboa; 2011.
- [10] Snyder B, Kaiser MJ. A comparison of offshore wind power development in Europe and the U.S.: patterns and drivers of development. *Appl Energy* 2009;86:1845–56.
- [11] National Renewable Energy Laboratory (NREL). Large-scale offshore wind power in the United States: Assessment of opportunities and barriers. (<http://www.nrel.gov/nwtc/>); 2010 [accessed 15.08.12].
- [12] American Wind Energy Association (AWEA). 20% Wind energy by 2030, (<http://www.nrel.gov/docs/fy08osti/41869.pdf>); 2008 [accessed 12.11.12].
- [13] U.S. Energy Information Administration (USEIA). Electric power annual report 2010. ([http://www.eia.gov/cneaf/electricity/epa/epa\\_sum.html](http://www.eia.gov/cneaf/electricity/epa/epa_sum.html)); 2011 [accessed 20.09.12].
- [14] U. S. Department of Energy (USDOE). Offshore wind market and economic analysis. ([http://www1.eere.energy.gov/wind/pdfs/offshore\\_wind\\_market\\_and\\_economic\\_analysis\\_10\\_2013.pdf](http://www1.eere.energy.gov/wind/pdfs/offshore_wind_market_and_economic_analysis_10_2013.pdf)); 2013 [accessed 25.11.13].
- [15] Omitaomu OA, Rose AN, Blevins BR, Jochem WC, Mays GT, Belles R. Adapting a GIS-based multicriteria decision analysis approach for evaluating new power generating sites. *Appl Energy* 2012;96:292–301.
- [16] Landry CE, Allen T, Cherry T, Whitehead JC. Wind turbines and coastal recreation demand. *Res Energy Econ* 2012;34:93–111.
- [17] O'Keefe A, Haggett C. An investigation into the potential barriers facing the development of offshore wind energy in Scotland: case study – first of forth offshore wind farm. *Renew Sustain Energy Rev* 2012;16:3711–21.
- [18] Vagiona DG, Karanikolas NM. A multicriteria approach to evaluate offshore wind farms sitting in Greece. *Glob NEST J* 2012;14:235–43.
- [19] Dvorak MJ, Archer CL, Jacobson MZ. California offshore wind energy potential. *Renew Energy* 2010;35:1244–54.
- [20] Esteban MD, Diez JJ, López JS, Negro V. Why offshore wind energy? *Renew Energy* 2011;36:444–50.
- [21] Tegou L, Polatidis H, Haralambopoulos DA. Environmental management framework for wind farm siting: methodology and case study. *J Environ Manag* 2010;91:2134–47.
- [22] Haggett C. Understanding public responses to offshore wind power. *Energy Policy* 2011;39:503–10.
- [23] Blyth-Skyrme RE. Options and opportunities for marine fisheries mitigation associated with windfarms. Summary report for COWRIE contract FISH-MITIG09. Newbury, UK: COWRIE Ltd, c/o Nature Bureau; 2010.
- [24] Firestone J, Kempton W, Krueger A. Public acceptance of offshore wind power projects in the USA. *Wind Energy* 2009;12:183–202.
- [25] Christidis T, Law J. Review: the use of geographic information systems in wind turbine and wind energy research. *J Renew Sustain Energy* 2012;4(1):012701–9.
- [26] Byrne J, Aiming Z, Shen B, Hughes K. Evaluating the potential of small-scale renewable energy options to meet rural livelihoods needs: a GIS and lifecycle cost-based assessment of Western China's options. *Energy Policy* 2007;35(8):4391–401.
- [27] Nguyen KQ. Wind energy in Vietnam: resource assessment, development status and future implications. *Energy Policy* 2007;35(2):1405–13.
- [28] Yue CD, Yang MH. Exploring the potential of wind energy for a coastal state. *Energy Policy* 2009;37(10):3925–40.
- [29] Ramachandra TV, Shruthi BV. Wind energy potential mapping in Karnataka, India, using GIS. *Energy Convers Manag* 2005;46(9):1561–78.
- [30] Aydin NY, Kentel E, Duzgun S. GIS-based environmental assessment of wind energy systems for spatial planning: a case study from Western Turkey. *Renew Sustain Energy Rev* 2010;14(1):364–73.
- [31] Voivontas D, Assimacopoulos D, Mourelatos A, Corominas J. Evaluation of renewable energy potential using a GIS decision support system. *Renew Energy* 1998;13(3):333–44.
- [32] Tegou L, Polatidis H, Haralambopoulos DA. Environmental management framework for wind farm siting: methodology and case study. *J Environ Manag* 2010;91:2134–47.
- [33] Hurtado JP, Fernandez J, Parrondo JL, Blanco E. Spanish method of visual impact evaluation in wind farms. *Renew Sustain Energy Rev* 2004;8(5):483–91.
- [34] Ramirez-Rosado IJ, Garcia-Garridoa E, Fernandez-Jimenez LA, Zorzano-Santamaria PJ, Monteiro C, Miranda V. Promotion of new wind farms based on a decision support system. *Renew Energy* 2008;33(4):558–66.
- [35] Moller B. Continuous spatial modelling to analyse planning and economic consequences of offshore wind energy. *Energy Policy* 2011;39(2):511–7.
- [36] Punt MJ, Groeneveld RA, Ierland EC, Van, Stel JH. Spatial planning of offshore wind farms: a windfall to marine environmental protection? *Ecol Econ* 2009;69(1):93–103.
- [37] Simão A, Densham PJ, Haklay M. Web-based GIS. for collaborative planning and public participation: an application to the strategic planning of wind farm sites. *J Environ Manag* 2008;90:2027–40.
- [38] Berry R, Higgs G, Fry R, Langford M. Web-based GIS. Approaches to enhance public participation in wind farm planning. *Trans GIS* 2011;15:147–72.

- [39] Dutra R, Szklo A. Assessing long-term incentive programs for implementing wind power in Brazil using GIS rule-based methods. *Renew Energy* 2008;33(12):2507–15.
- [40] Bishop ID, Stock C. Using collaborative virtual environments to plan wind energy installations. *Renew Energy* 2010;35(10):2348–55.
- [41] Janke JR. Multicriteria GIS modeling of wind and solar farms in Colorado. *Renew Energy* 2010;35(10):2228–34.
- [42] Gorsevski PV, Cathcart SC, Mirzaei G, Jamal MM, Ye X, Gomezdelcampo E. A group-based spatial decision support system for wind farm site selection in northwest Ohio. *Energy Policy* 2013;55:374–85.
- [43] Baban SMJ, Parry T. Developing and applying a GIS-assisted approach to locating wind farms in the UK. *Renew Energy* 2001;24:59–71.
- [44] Gorsevski PV, Jankowski P. An optimized solution of multi-criteria evaluation analysis of landslide susceptibility using fuzzy sets and Kalman filter. *Comput Geosci* 2010;36(8):1005–20.
- [45] Gorsevski PV, Jankowski P, Gessler PE. An heuristic approach for mapping landslide hazard by integrating fuzzy logic with analytic hierarchy process. *Control Cybern* 2006;35(1):121–46.
- [46] Gorsevski PV, Donevska KR, Mitrovski CD, Frizado JP. Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: a case study using ordered weighted average. *Waste Manag* 2012;32(2):287–96.
- [47] Beacham JL, Jensen JR, Wang Z. A feasibility analysis of South Carolina wind resources for electric power generation. Columbia, South Carolina: Institute for Public Service and Policy Research, University of South Carolina; 2009.
- [48] Schillings C, Wanderer T, Cameron L, Wal JT, Jacquemin J, Veum K. A decision support system for assessing offshore wind energy potential in the North Sea. *Energy Policy* 2012;49:541–51.
- [49] Malczewski J. GIS-based multicriteria decision analysis: a survey of the literature. *Int J Geogr Inf Sci* 2006;20:703–26.
- [50] Malczewski J. GIS and multicriteria decision analysis. New York, NY: John Wiley and Sons Inc.; 1999.
- [51] Barton J, Plume J, Parolin B. Public participation in a spatial decision support system for public housing. *Comput, Environ Urban Syst* 2005;29:630–52.
- [52] Jelokhani-Niaraki M, Malczewski J. A user-centered multicriteria spatial decision analysis model for participatory decision making: an ontology-based approach. *Proceedings of global geospatial conference*. Canada: Québec City; 2012.
- [53] Tang MY. Design and implementation of a GIS-enabled online discussion forum for participatory planning. *Proceedings of the 4th annual PPGIS conference*. Cleveland, Ohio: Cleveland State University; 2006.
- [54] Trang NT. PGIS's relevance, applicability and conditions in local rural development: a case study with village development planning in Bach Ma National Park buffer zone, Vietnam. Enschede, the Netherlands: International Institute for Geo-Information Science and Earth Observation; 2004.
- [55] Cinderby S. Geographic information systems (GIS) for participation: the future of environmental GIS? *Int J Environ Pollut* 1999;11:304–15.
- [56] Balram S, Dragičević S. Collaborative geographic information systems. Hershey, PA: Idea Group Publishing; 2006.
- [57] Jankowski P, Nyerges T. Toward a framework for research on geographic information-supported participatory decision-making. *URISA J* 2003;15:9–17.
- [58] Jankowski P, Zielinska A, Swobodzinski M. Choice modeler: a web-based spatial multiple criteria evaluation tool. *Trans GIS* 2008;12:541–61.
- [59] Wang L, Cheng Q. Web-based collaborative decision support services: concept, challenges and application. *ISPRS Technical Commission II Symposium*, Vienna; 2006.
- [60] Meng Y, Malczewski J. Web-PPGIS usability and public engagement: a case study in canmore, Alberta, Canada. *URISA J* 2010;22(1):55–64.
- [61] Boroushaki S, Malczewski J. Participatory GIS: a web-based collaborative GIS and multicriteria decision analysis. *URISA J* 2010;22:23–32.
- [62] Rambaldi G, Kyem P, McCall M, Weiner D. Participatory spatial information management and communication in developing countries. *Electron J Inf Syst Dev Ctries* 2006;25:1–9.
- [63] Kubota S, Soga K, Sasaki Y, Abe A. Web GIS-based regional social networking service as participatory GIS. *LNEE* 157 2012;2:313–21.
- [64] Musungu K, Motala S. Participatory multi-criteria evaluation and GIS: an application in flood risk analysis. *FIG Young Surveyors Conference – Workshop 1.2*, 6204; 2012.
- [65] Alesheikh A, Helali H, Behroz H. Web GIS: technologies and its applications. *symposium on geospatial theory, processing and applications*, Ottawa; 2002.
- [66] Jankowski P, Stasik M. Spatial understanding and decision support system: A prototype for public GIS. *Trans GIS* 1997;2:73–84.
- [67] Sidlar CL, Rinner C. Analyzing the usability of an argumentation map as a participatory spatial decision support tool. *URISA J* 2007;19:47–55.
- [68] Rinner C, Keßler C, Andrusis S. The use of web 2.0 concepts to support deliberation in spatial decision-making. *Comput, Environ Urban Syst* 2008;32(5):386–95.
- [69] Karnatak HC, Saran S, Bhatia K, Roy PS. Multicriteria spatial decision analysis in web GIS environment. *Geoinformatica* 2007;11:407–29.
- [70] Mansourian A, Taleai M, Fasihi A. A web-based spatial decision support system to enhance public participation in urban planning processes. *J Spatial Sci* 2011;56:269–82.
- [71] Brown G, Weber D. Using public participation GIS (PPGIS) on the Geoweb to monitor tourism development preferences. *J Sustain Tour* 2013;21:192–211.
- [72] Zhong T, Young RK, Lowry M, Rutherford GS. A model for public involvement in transportation improvement programming using participatory geographic information systems. *Comput, Environ Urban Syst* 2008;32:123–33.
- [73] Sun A. Enabling collaborative decision-making in watershed management using cloud-computing services. *Environ Model Softw* 2013;41:93–7.
- [74] Zhang Y, Sugumaran R, McBroom M, DeGroot J, Kauten RL, Barten PK. Web-based spatial decision support system and watershed management with a case study. *Int J Geosci* 2011;2:195–203.
- [75] Mari R, Bottai L, Busillo C, Calatrini F, Gozzini B, Gualtieri G. AGIS-based interactive web decision support system for planning wind farms in Tuscany (Italy). *Renew Energy* 2011;36:754–63.
- [76] Taranu J. Building consensus using a collaborative spatial multi-criteria analysis system. (M.Sc. thesis). University of Waterloo; 2009.
- [77] Emerson P. The original Borda count and partial voting. *Soc Choice Welf* 2011;40:353–8.
- [78] Zarghami M. Soft computing of the Borda count by fuzzy linguistic quantifiers. *Appl Soft Comput* 2011;11:1067–73.
- [79] Munda G. Social multi-criteria evaluation for a sustainable economy. Berlin, Germany: Springer; 2008.
- [80] Ratliff TC. A comparison of Dodgson's method and the Borda count. *Econ Theory* 2002;20(2):357–72.
- [81] U.S. Census Bureau. (<http://quickfacts.census.gov/qfd/states/39000.html>); 2010 [Accessed October 20, 2012].
- [82] Holcombe TL, Taylor LA, Reid DF, Warren JS, Vincent PA, Herdendorf CE. Revised Lake Erie postglacial lake level history based on new detailed bathymetry. *J Great Lakes Res* 2003;29:681–704.
- [83] Herdendorf CE. Lake Erie coastal wetlands: an overview. *J Great Lakes Res* 1992;18:533–51.
- [84] Great Lakes Wind Energy Center (GLWEC). Feasibility study, Final Feasibility Report, Cleveland, Ohio; 2009.
- [85] Kunkel KE, Westcott NE, DAR Kristovich. Assessment of potential effects of climate change on heavy lake-effect snowstorms near Lake Erie. *J Great Lakes Res* 2002;28:521–36.
- [86] U. S. Department of Energy (USDOE). National offshore wind strategy: creating an offshore wind energy industry in the United States. (<http://www1.eere.energy.gov/wind/>); 2011 [accessed 25.08.12].
- [87] Lake Erie Energy Development Corporation (LEEDCo). (<http://www.leedco.org/>); 2011 [accessed 25.10.12].
- [88] Truewind AWS. Great lakes offshore wind power project. Albany, NY: Site Screening Study for Potentially Viable Offshore Wind Energy Sites; 2010.
- [89] Helimax Energy Inc. (HEI). Analysis of future offshore wind farm development in Ontario, Canada; 2008.
- [90] Guarnaccia J, Kerlinger P. Feasibility study of potential avian risk from wind energy development. Lucas, Ottawa, Sandusky, and Erie Counties, Ohio: Western Ohio Lakeshore Region; 2007.
- [91] Ohio Audubon Society. Important Bird Areas (IBA). (<http://web4.audubon.org/bird/iba/>); 2012 [accessed 08.08.12].
- [92] Baisner AJ, Andersen JL, Findsen A, Granath SW, Madsen KØ. Minimizing collision risk between migrating raptors and marine wind farms: development of a spatial planning tool. *Environ Manag* 2010;46:801–8.
- [93] Ohio Department of Natural Resources (ODNR). Offshore wind energy. (<http://www.ohiodnr.com/LakeErie/WindEnergyRules/tabid/21234/Default.aspx>); 2012 [accessed 10.12.12].
- [94] Insua DR, Kersten GE, Rios J, Grima C. Towards decision support for participatory democracy. *Inf Syst e-Bus Manag* 2008;6:161–91.